UNITED STATES AIR FORCE MATERIALS TECHNOLOGY HIGHLIGHTS

Air Force Research Laboratory
Materials & Manufacturing Directorate

Wright-Patterson Air Force Base • Dayton, Ohio Summer 2004

Researchers Develop Super-High Strength Aluminum Alloys for Cryogenic Applications

Scientists at the Air Force Research Laboratory's Materials and Manufacturing Directorate (ML) have developed a super-high strength aluminum alloy that can be used to improve the performance and capability of aerospace components, specifically for cryogenic rocket engine applications.

Researchers have successfully achieved an alloy with specific strength and ductility characteristics that surpass those of the alpha titanium alloy currently used in rocket engine turbopump impellers. The aluminum alloy has also demonstrated less sensitivity to hydrogen, a weight advantage and the tremendous potential for cost-savings related to its manufacturing and maintenance, as compared to the titanium alloy.

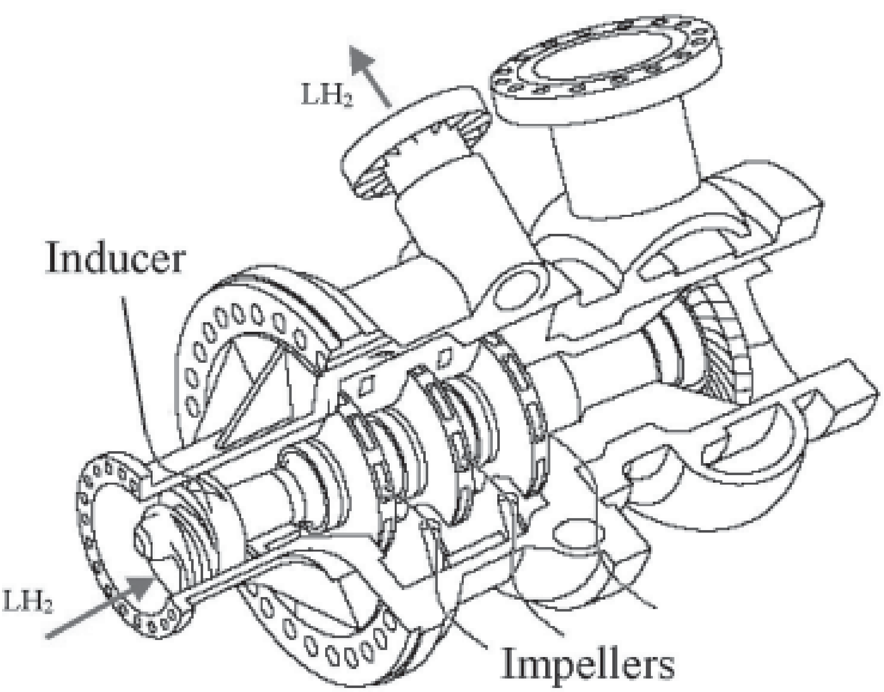
The currently used alloy has been made in castings that are 76 millimeters in diameter and six meters long. When this achievement is demonstrated at the full-scale, scientists expect that the alloys will be appropriate for additional applications, and that streamlined manufacturing processes and cost reductions will benefit the Air Force, Department of Defense, and industry.

In liquid rocket engines, which use liquid hydrogen (LH_2) as fuel and liquid oxygen as an oxidizer, components must function at cryogenic temperatures of 20 Kelvin or –253° Centigrade. Turbopumps in a rocket's engine, like the Integrated Powerhead Demonstrator (IPD) turbopump, perform the duty of moving liquid hydrogen and oxygen at high speeds through pipes from the storage cryogenic tanks to the rocket's combustion chamber.

The ML team's goal was to improve thrust-to-weight ratio in rocket engines by identifying an aluminum alloy with specific strengths that equal or exceed those of the high-strength titanium alloy (Ti-5Al-2.5Sn ELI) used for turbopump impellers. The aluminum alloy was also required to provide a significant reduction in weight. In addition, the scientists sought to achieve strength properties in an aluminum alloy under conditions of no less than seven percent ductility.

To date, the program has resulted in a super-high strength cast and wrought Al alloy, which has specific strength that exceeds the specific strength of the current titanium alloy, at the same ductility. During follow-on testing, scientists will produce larger cast billets and forgings in order to prove full-scale achievement. They will also complete certification of the forging preforms to determine tensile properties of different parts of forging, notch sensitivity, fracture toughness and high cycle fatigue response. They will also conduct additional fluidity and tensile property testing to prove the casting ability of the selected alloy.

Part of the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) program, advancements achieved here are expected to result in a reduction in weight and significant improvement in the performance of vital spacecraft propulsion components. Directorate scientists and engineers demonstrated the feasibility of using super-high strength aluminum alloys to fabricate component parts for spacecraft propulsion. The project team succeeded in achieving desired properties during testing with half-sized, sub-scale preforms. The aluminum alloy is significantly less expensive, more resistant to hydrogen embrittlement, (continued on page 4)



The LH_2 Turbopump (courteousy of Boeing-Rocketdyne)

Scientists Prove Fluids Unnecessary For Hydraulic Component Shipping And Storage

Scientists and engineers from the Air Force Research Laboratory's Materials and Manufacturing Directorate (ML) recently completed a program, funded by the Aeronautical Systems Center (ASC), to prove that storing and shipping aircraft hydraulic components in barium-containing fluids provides no additional rust inhibiting advantage over storing or shipping them in operational fluids.

Following three years of extensive storage testing, personnel from the directorate's Nonmetallic Materials Division have determined that using operational fluid in lieu of rust inhibited fluids will reduce the hazardous waste stream associated with the barium-containing fluids, eliminate a source of aircraft operational problems, and consolidate the number of fluids in the Air Force inventory.

ML researchers from the directorate's Fluids and Lubricants Group carefully developed and executed a pollution prevention program that suggests aircraft components can be stored in their operational fluids for lengthy periods of time without the onset of rust or corrosion. The results suggest the Air Force can eliminate the requirement for several thousand gallons of barium-containing, rust inhibited fluids, and the time and cost burdens associated with procurement of these fluids and disposing of their waste.

The practice of using barium dinonylnaphthalene sulfonate (BSN), an additive in rust inhibited fluid, for the shipment and storage of aircraft components can be attributed to several military technical orders. In accordance with these technical orders, when a component is needed, it is removed from storage, the rust inhibited fluid is drained and discarded and the component is installed. However, because the rust inhibited fluid includes a barium-containing additive, environmental regulations have designated the fluid as a hazardous waste, which requires careful handling and additional disposal expense. In addition, BSN contamination has been linked to operational problems, including sticking valves, in Army, Navy and Air Force aircraft where components hadn't been drained thoroughly enough before they were installed.

In the mid-1990s, scientists and engineers from the Materials and Manufacturing Directorate's Fluids and Lubricants Group submitted a formal suggestion that the Air Force stop using rust inhibited fluids for shipment and storage. Representatives from the group could not find documentation supporting the use of inhibited fluids, and they recognized the reduced logistical burden and cost savings associated with removing two rust inhibited fluids from the Air Force inventory. By storing components in their operational fluid, the group suggested that the Air Force could also eliminate additional work for component suppliers, overhaulers and aircraft maintainers. The aircraft system program offices (SPOs) however wanted proof of the concept.

Ms. Lois J. Gschwender, a senior materials research engineer from the Materials and Manufacturing Directorate, examines one of the specimens that was stored in the directorate's Oxidation and Corrosion Laboratory.

In order to validate their suggestion, the group designed a pollution prevention program and received the funding needed to execute it from the Aeronautical Systems Center's Pollution Prevention Branch (ASC/ENVV) in 1998. Prior to initiating the program, which would include several years of component storage in military specified rust inhibited and operational fluids, the group surveyed a variety of military corrosion experts, aircraft maintainers and system program offices (SPOs) for their input. Based on the input and requests of those contacted, a test matrix was established, test articles were selected, and storage tests began.

In April 2000, the group selected steel bearings, which were donated by Timken Bearing Co., and pistons from F-16 hydraulic pumps from the field, as test articles. These components were put in jars with a variety of fluids including: MIL-PRF-6083 and MIL-PRF-46170, which are rust inhibited fluids; and MIL-PRF-83282, MIL-PRF-87257, and MIL-PRF-5606, which are operational fluids. Water contamination was introduced to some of the jars. In June and July 2000, the group also began storing F-16 hydraulic pumps in a matrix of the barium-containing storage fluids and barium-free operational fluids (some of which were contaminated with 300 parts per million, or ppm, of water). All of the jars and the pumps were stored at ML's Wright-Patterson AFB research complex for three years.

To date, personnel from the group haven't observed any changes in the bearings or pistons, except for some slight discoloration and a red gel in subjects containing the MIL-PRF-46170 fluid where 200 and 400 ppm of water were added. In addition, they noticed no change in pumps that were stored in operational fluids. However, during an inspection of a MIL-PRF-46170-filled pump, personnel noticed that a main bearing resisted turning and that the metal had become discolored.

Based on the results of this testing, the Air Force has already modified a technical order (TO 42B2-1-3) for hydraulic equipment to allow for storage with operational fluid with SPO agreement, and the Army plans to discontinue MIL-PRF-46170, type II aircraft storage fluid from the specification. A final technical report is being written and a workshop is being organized to disseminate the results of the program to Air Force SPOs, field level maintainers, component manufacturers and suppliers, and aircraft users.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 04-041 .

ML Acquires Advanced Secondary Ion Mass Spectrometry Surfaces Analysis System

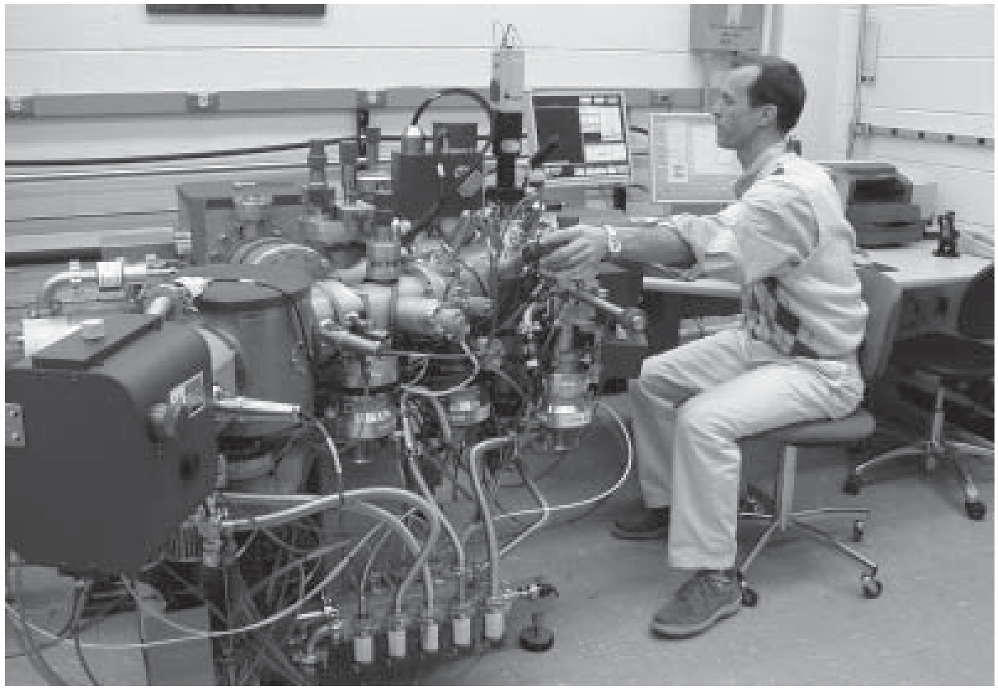
Scientists and engineers at the Air Force Research Laboratory Materials and Manufacturing Directorate (ML), with assistance from the Air Force Office of Scientific Research, have acquired a highly advanced materials analysis system capable of analyzing the surface and in-depth composition of materials with sensitivities as high as parts per billion. The new system provides *Secondary Ion Mass Spectrometry* (SIMS) capability that dramatically increases the ability to identify and quantify various types of materials, including dopants (materials added to crystals to change the physical properties), impurities and contaminants.

The newly acquired SIMS technology provides scientists and engineers in the ML Survivability and Sensor Materials Division with the most highly advanced in-house capability of its kind in the Air Force. The improved capabilities provided by this advanced materials analysis system will ultimately help improve the performance and reliability of critical aerospace systems and subsystems, and will greatly enhance the reputation of the Air Force Research Laboratory as a "center of excellence" for materials and manufacturing research and development.

In November 2003, ML tested and accepted a new magnetic sector type SIMS, used to analyze materials surfaces and depth composition. The new system is extremely sensitive (it can measure in parts per billion) and represents a significant improvement over analysis systems currently in use at the Air Force Research Laboratory. It was installed in the Analytical Surface Spectroscopy Laboratory, operated by researchers in the Survivability and Sensor Materials Division.

SIMS is a highly sophisticated analytical technique that combines focused primary ion beam bombardment with mass spectrometry of sputtered (ejected) secondary ions to achieve high sensitivity and high elemental selectivity. The technology has several applications important to Air Force materials and manufacturing research and development efforts. It can be used to identify and quantify all dopants, impurities and surface contaminants, metals (including aircraft corrosion samples), dielectrics, coatings, thin films and a number of other important materials.

SIMS technology provides the much-needed capability for high sensitivity, three-dimensional, elemental analysis of molecular structure. There are three basic types of SIMS.



A research scientist at the Materials and Manufacturing Directorate fine-tunes the newly acquired Secondary Ion Mass Spectrometry (SIMS) analysis system. The new system is the highest resolution system of its kind in the Air Force and is capable of analyzing materials surfaces and depth composition with sensitivities as high as parts per billion.

The first is *Static* SIMS, used for surface analysis. In this instance, low-energy primary ions are used to dislodge secondary ions from the surface layers. The secondary ions are then analyzed by mass spectrometry to produce a spectrum, which can be used to identify organic and inorganic species. *Imaging* SIMS is used for spatial analysis, and involves scanning the primary ion beam over the surface to build up an image that reveals the distribution of species. The third type of SIMS is *Dynamic* SIMS and is used for depth analysis. Using this method, surface layers are progressively etched away by concentrating the primary ion beam into a small, concise area. This allows an analysis of the subsurface region, whereby depth profiles are built up by correlating the etch time with intensity for different species. The goal of depth profiling is to obtain information on the variation of composition below the initial surface. This type of information is very useful for analysis of layered structures such as those produced in the semiconductor industry.

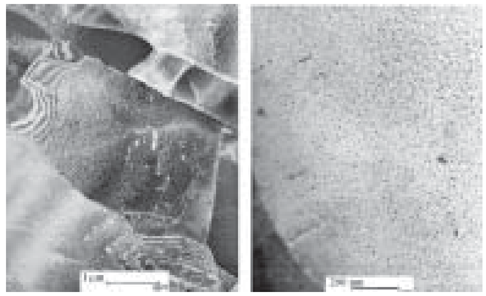
Because Dynamic SIMS relies on the removal of atoms from the surface of a material, it is a destructive technique; nevertheless, it is ideally suited for depth profiling applications. Hence, a depth profile of a sample may be obtained simply by recording sequential SIMS spectra as the surface is gradually eroded away by the incident ion beam probe. A plot of the intensity of a given mass signal, as a function of time, is a direct reflection of the variation of its abundance/concentration with depth below the surface.

One of the principal advantages SIMS offers over other depth profiling techniques (i.e., *Auger* depth profiling) is its sensitivity to very low concentrations of elements. This is especially important in the semiconductor industry, where dopants are often present at very low concentrations. Some of the key applications of SIMS include education and research; chemical analysis of surfaces and mapping distribution of species; contamination analysis of thin films and surfaces; monitoring the continuity of surface coatings; failure analysis of thin film devices; and development of bioactive surfaces. Applications include semiconductors, aircraft corrosion samples, and other materials all of which are important to current and future aerospace systems designed to support the warfighter and national defense.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 03-561.

(continued from page 1)
and is 38 percent lighter than the conventional titanium alloys currently used in propulsion systems.

Advances in propulsion achieved during this effort will help achieve the goals of the IHPRPT program. IHPRPT is a Department of Defense, National Aeronautics and Space Administration, and industry coordinated effort that provides maximum connectivity among various propulsion activities. The goal of the program is to develop revolutionary and innovative technologies by the year 2010 that will enable a doubling of rocket propulsion capabilities over 1993 state-of-the-art technology. The program will improve the nation's capability to move into full-scale development of rocket propulsion systems with improved performance, affordability, operability, reliability, and maintainability.



The microstructure of extruded and aged alloy specimens. These images were taken with a transmission electron microscope.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 04-046 .

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